SMA Interferometry School 2020

Calibration II

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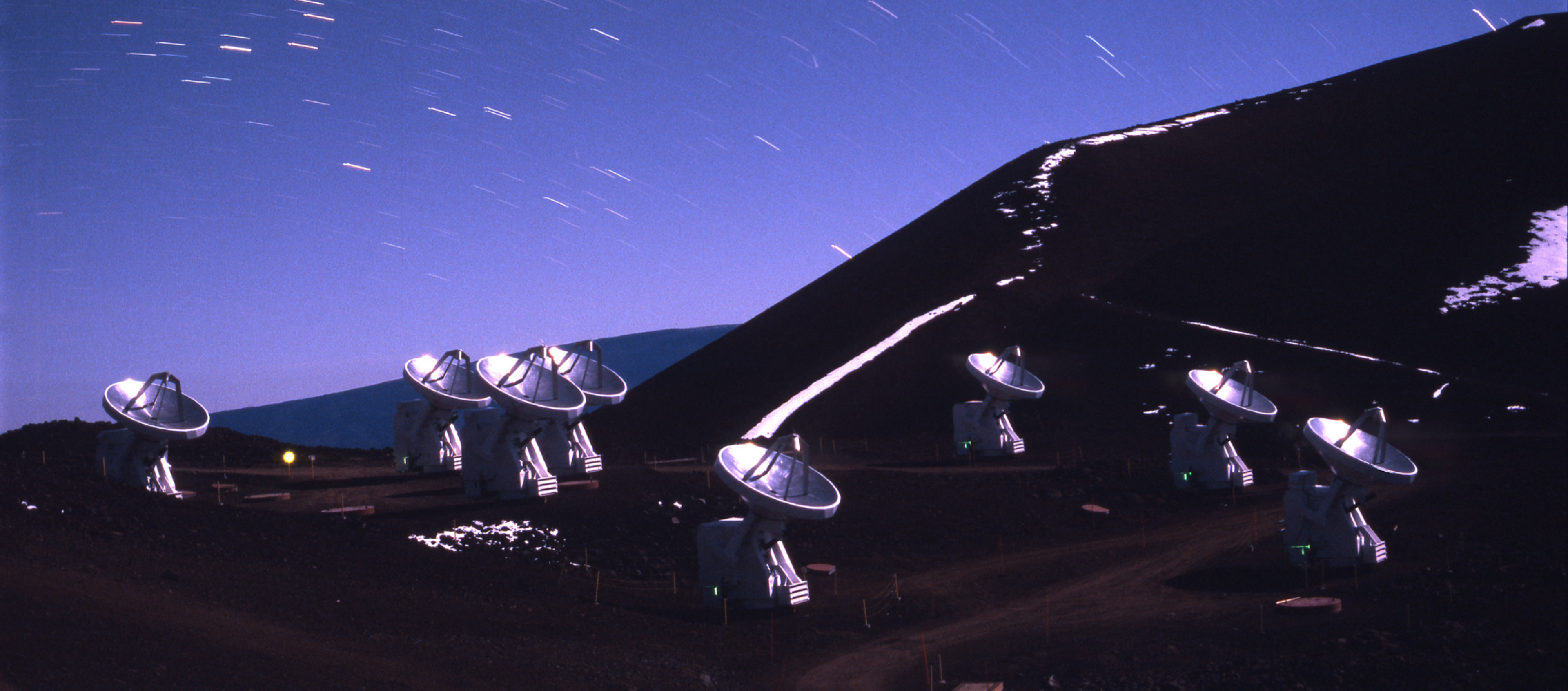


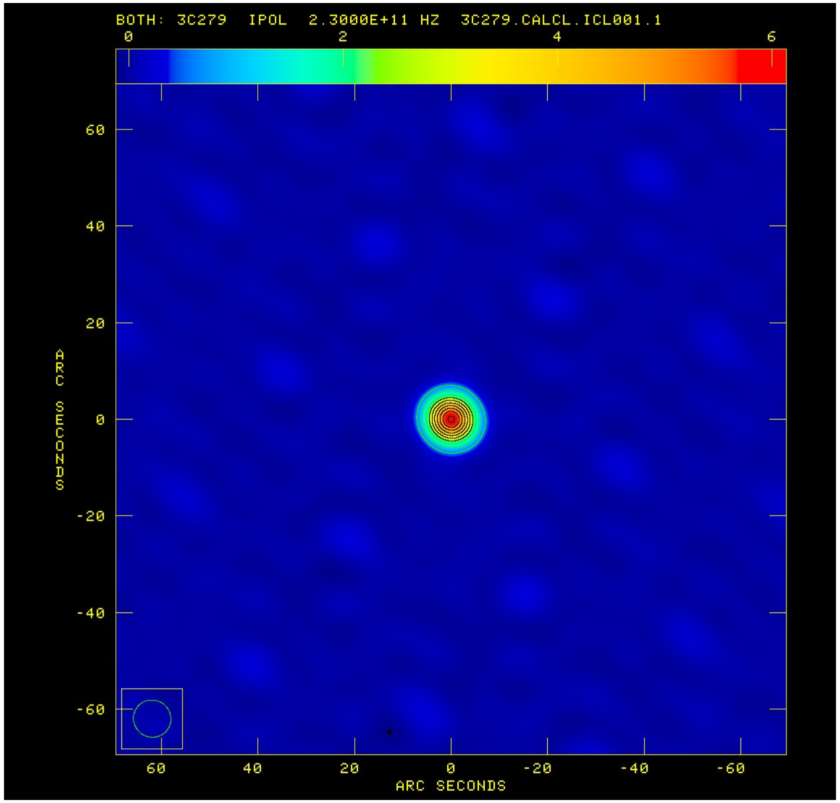
Outline

- Further gain calibration considerations
  - what makes a good calibrator
  - use of multiple phase reference calibrators
- Phase self-calibration
  - why it can improve data, and at what cost
  - when is self-cal not appropriate?
- Flux calibration
  - use of solar system objects
  - desperate alternatives

Gain calibration

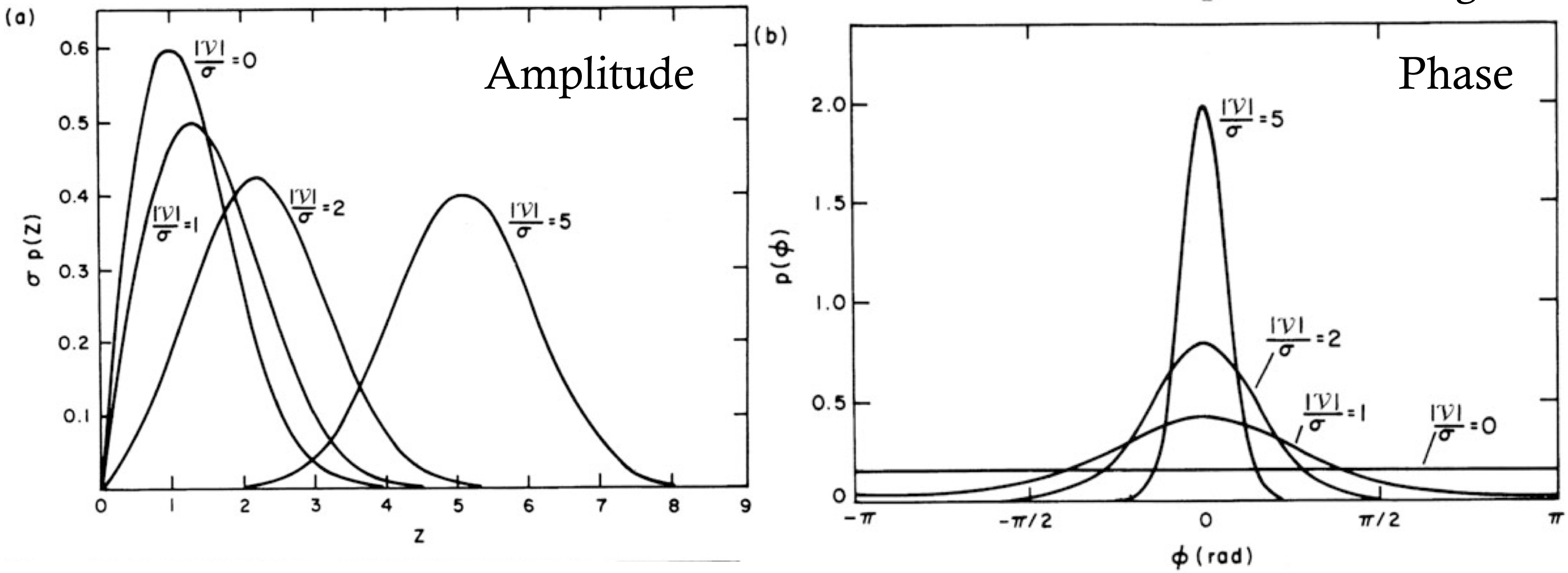
Gain calibration – Properties of a good calibrator

- Bright, point-like, with well known position
- ’Close’ to your target
- Low variability during observations



How ‘bright’ is bright?

TMSIII fig 6.9



Need SNR to determine phase (and amplitude) of calibrator to ‘required’ precision in a ‘reasonable’ time.

For $SNR_{Thermal} >> 1$, $\sigma_A \sim \sigma_\varphi \sim 1/SNR$

Workin' the numbers

$$S_{\text{rms}} = \frac{2kT_S}{A\eta_A \sqrt{n_a(n_a - 1)\Delta\nu_{\text{IF}}\tau_0}} = 41 \text{ mJy}$$

T_S = 300 K

A = 28.27 m^2 (6-m dish)

η_A = 0.75 (aperture efficiency)

n_a=2 (1 Baseline)

$\Delta\nu_{\text{IF}}$ = 8 GHz

τ_0 = 60 s

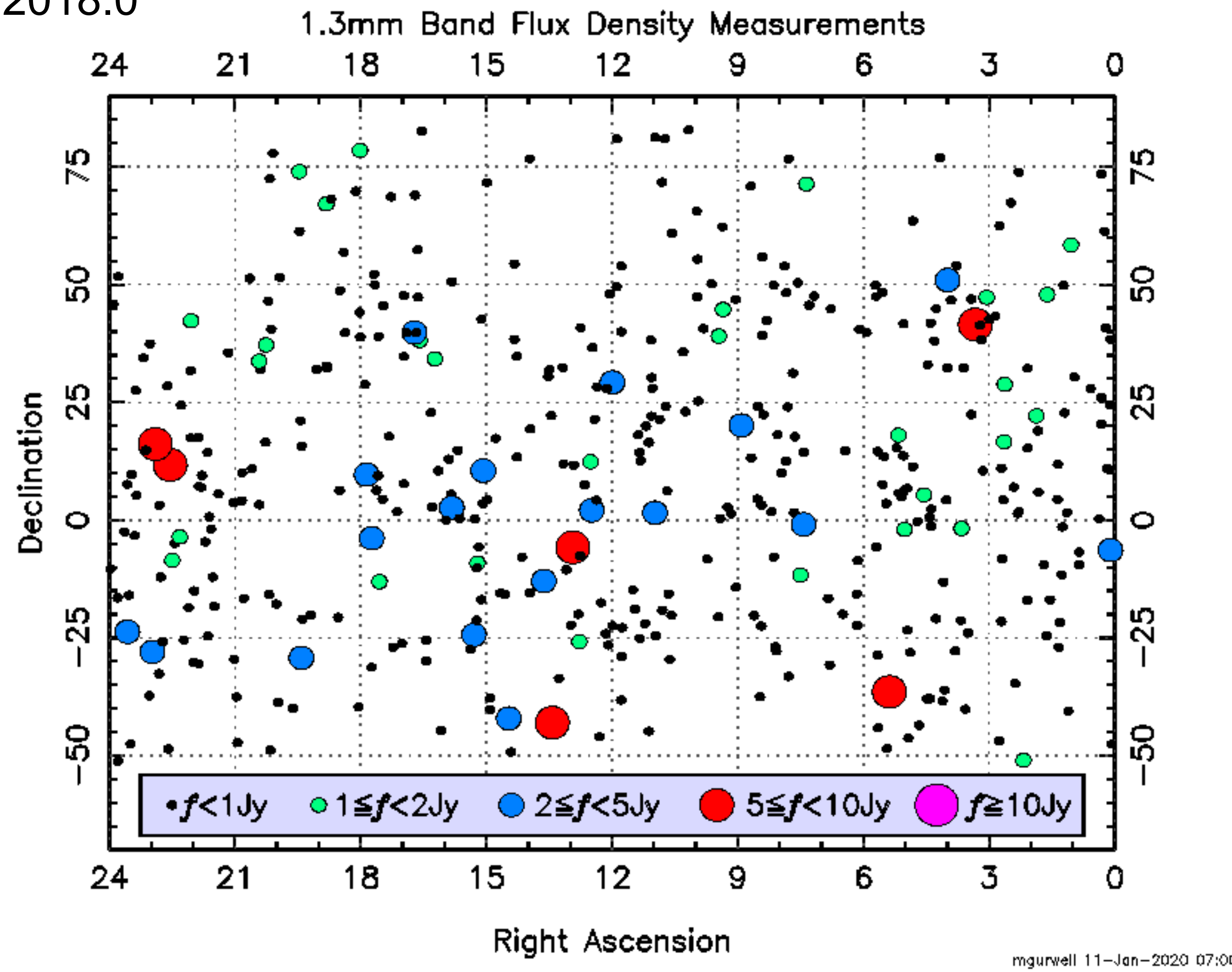
Workin' the numbers

$$S_{\mathrm{rms}} = \frac{2kT_S}{A\eta_A \sqrt{n_a(n_a - 1)\Delta\nu_{\mathrm{IF}}\tau_0}} = 41 \text{ mJy}$$

So, in this example, to reach an SNR of 10 (or 20) in 60 s, need to have a calibrator $\gtrsim$400 (or 800) mJy.

Calibrator Sky Coverage

2018.0



What is ‘close enough’?

Practical considerations –

Rise/set of calibrator relative to target

for 15°, up to 1 hour difference in rise/set times

Atmospheric path differences

for 15°, at low el, difference over one in airmass

In mm/submm may not have much choice, as ‘strong’ sources are not well distributed

Anecdotally, within 15 is ‘ok’, 10 degrees is ‘pretty good’ if you can get it, and within 5 degrees is ‘fantastic’.

Multi-calibrator Strategy

Useful to ameliorate calibrator distance issues

- Pick two (or more) similar strength calibrators, bracketing target such that one is always available

- Pick a weaker, closer calibrator and a stronger more distant calibrator.

Self-calibration

What is self-calibration?

Using the target data to determine gain solutions (typically phase, can include amplitude) via comparison with a ‘model’.

General phase calibration is a simple case of self-calibration, with the ‘model’ a point source at a known position (with the solutions interpolated to the target).

Why use self-calibration?

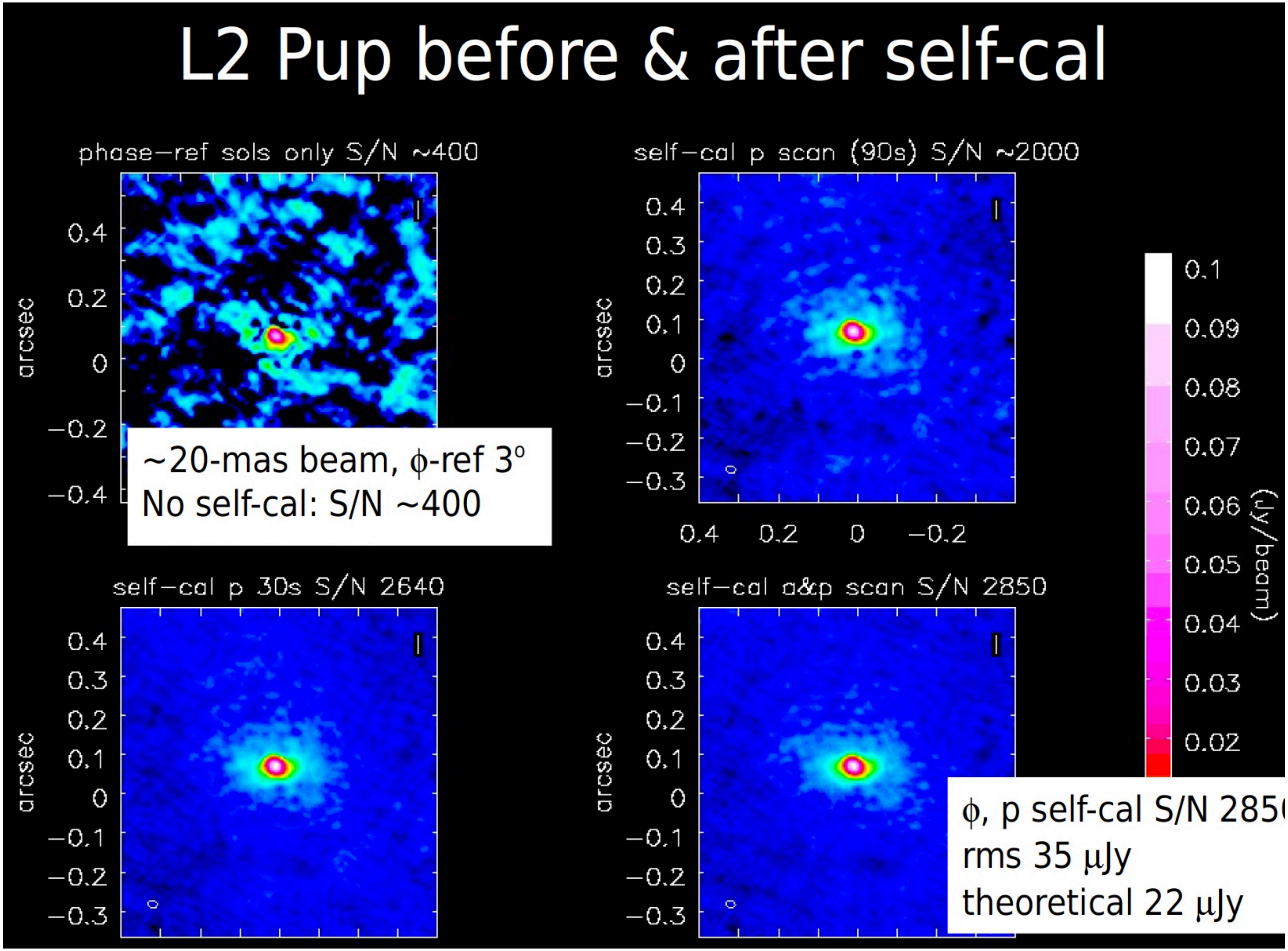
Improve the image signal-to-noise ratio and fidelity

Overcome dynamic range limitations

The atmosphere is similar, not identical, above the target and above the phase-ref

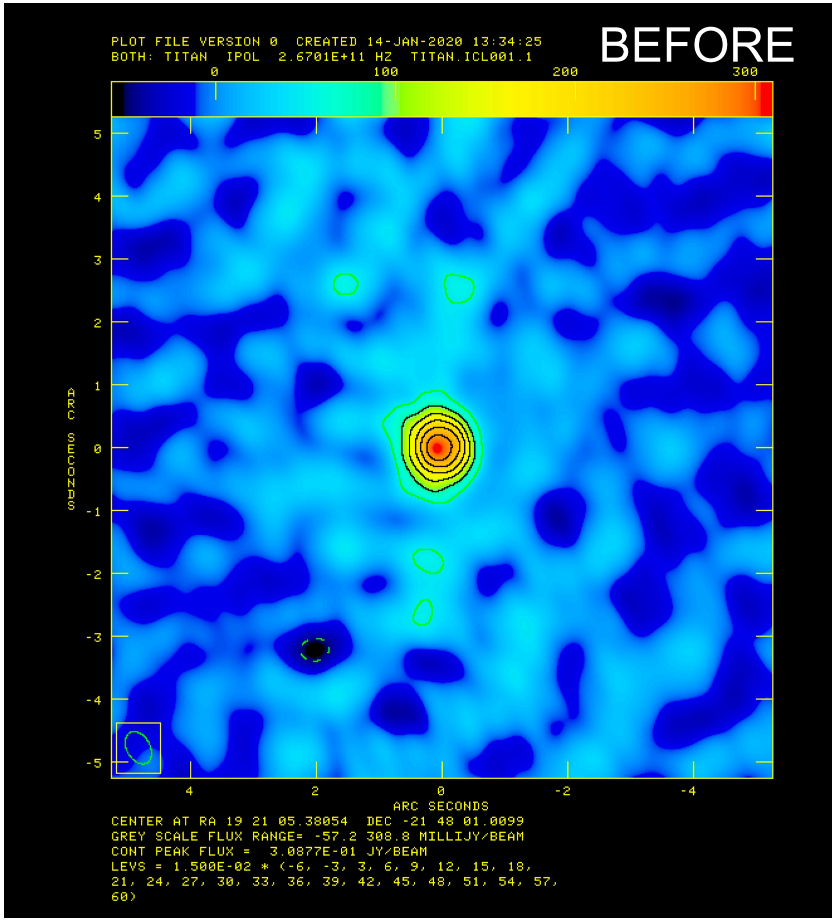
The phase-ref may be fainter than the target, so solutions are less accurate in both time and location

ALMA example (Anita M.S. Richards, UK ARC Node)

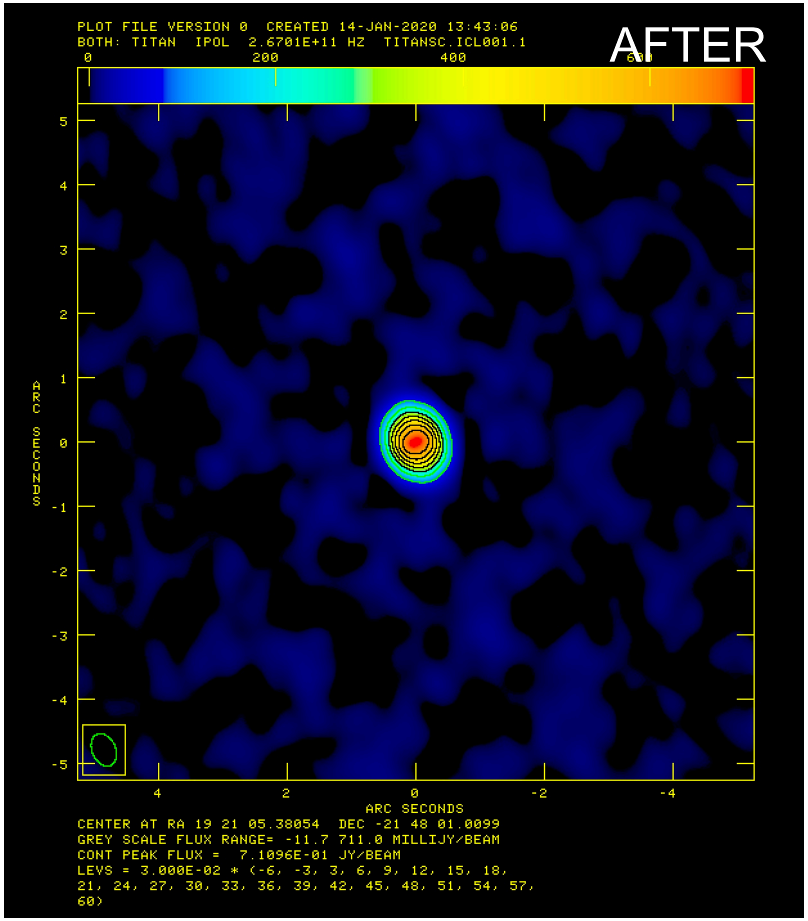


SMA example

(Titan, June 18, 2019 VEX at 267 GHz)



Dynamic Range~20



Dynamic Range~230

Caveats

Self-calibration disengages absolute astrometry; can't use self-cal to determine a position 'better'

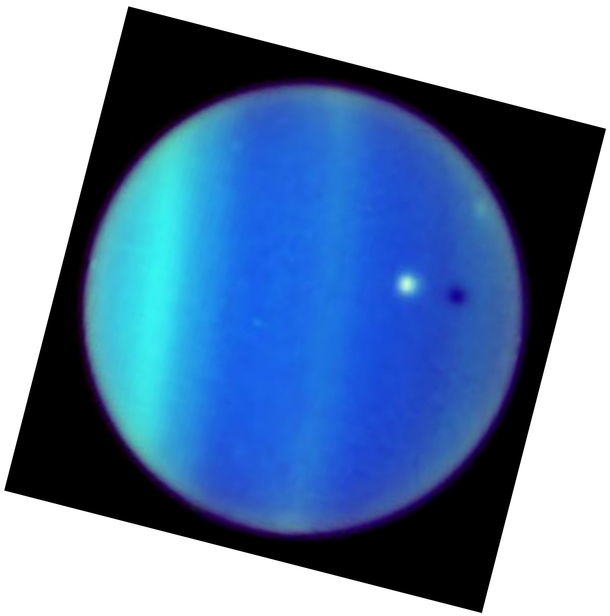
Typically requires target strength to be strong enough for a good detection (antenna-based) in a time short enough to remove atmospheric fluctuations. If you have to average in time over too long, you will only decorrelate your source signal.

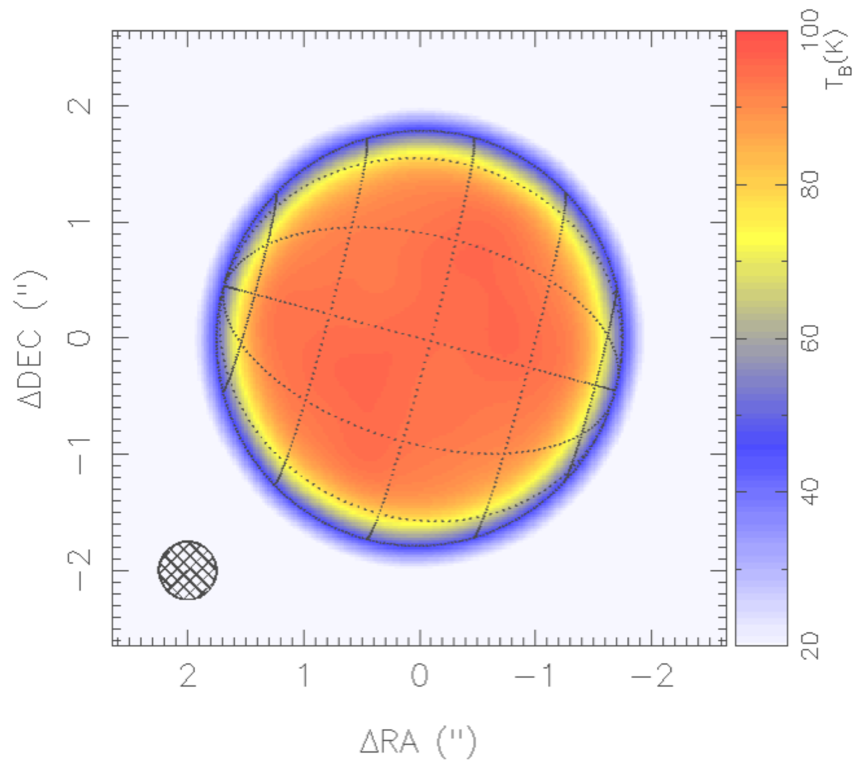
Model must be very accurate and/or number of baselines should be large. 8 antennas is a bit 'light', but if model is very good it works.

Flux calibration

Absolute Flux Calibration

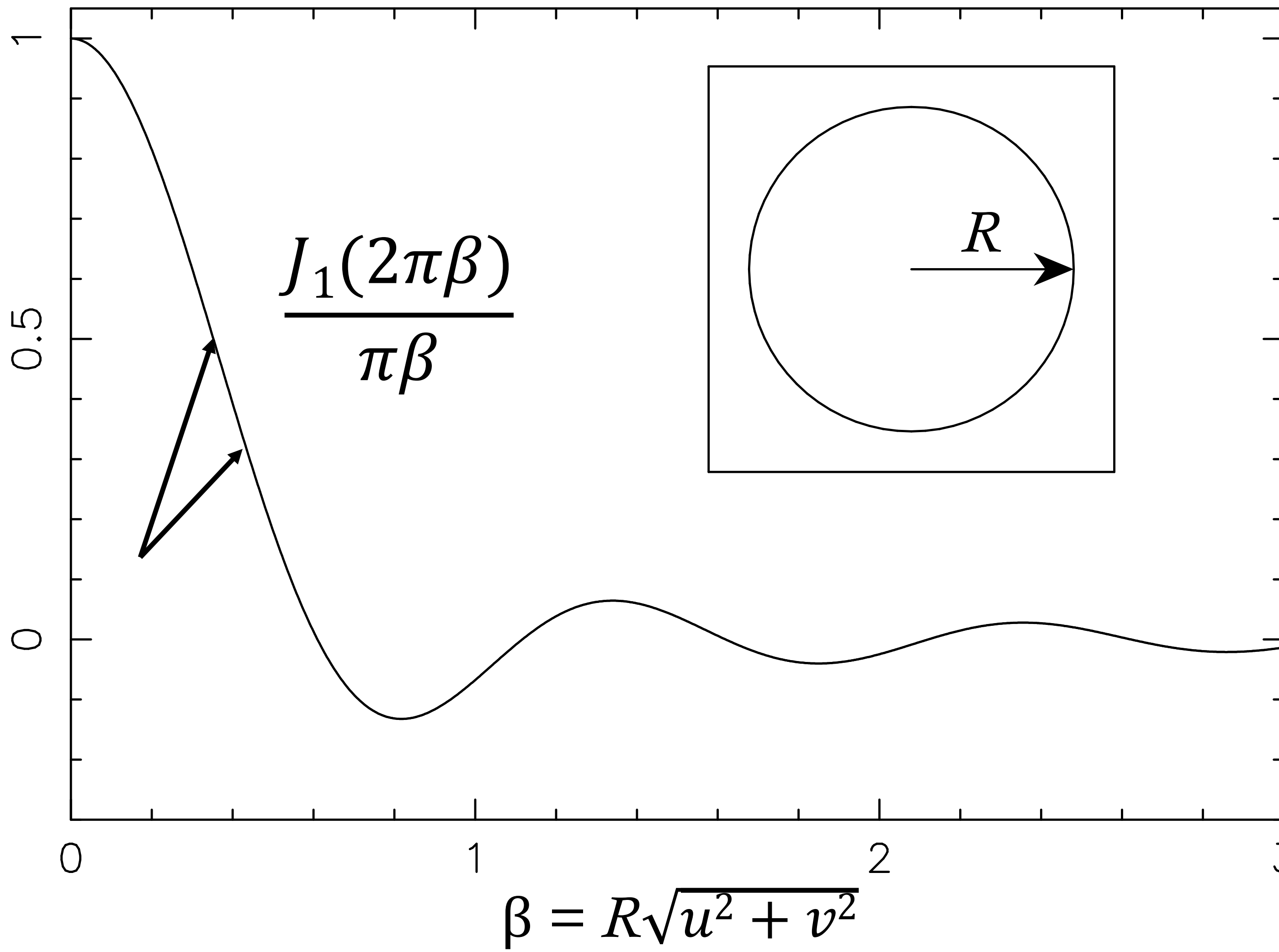
“That’s no moon. It’s a ~~space station~~ flux calibrator.”





(Reference: Butler 2012, ALMA Memo 594)

Visibility of a uniform disk

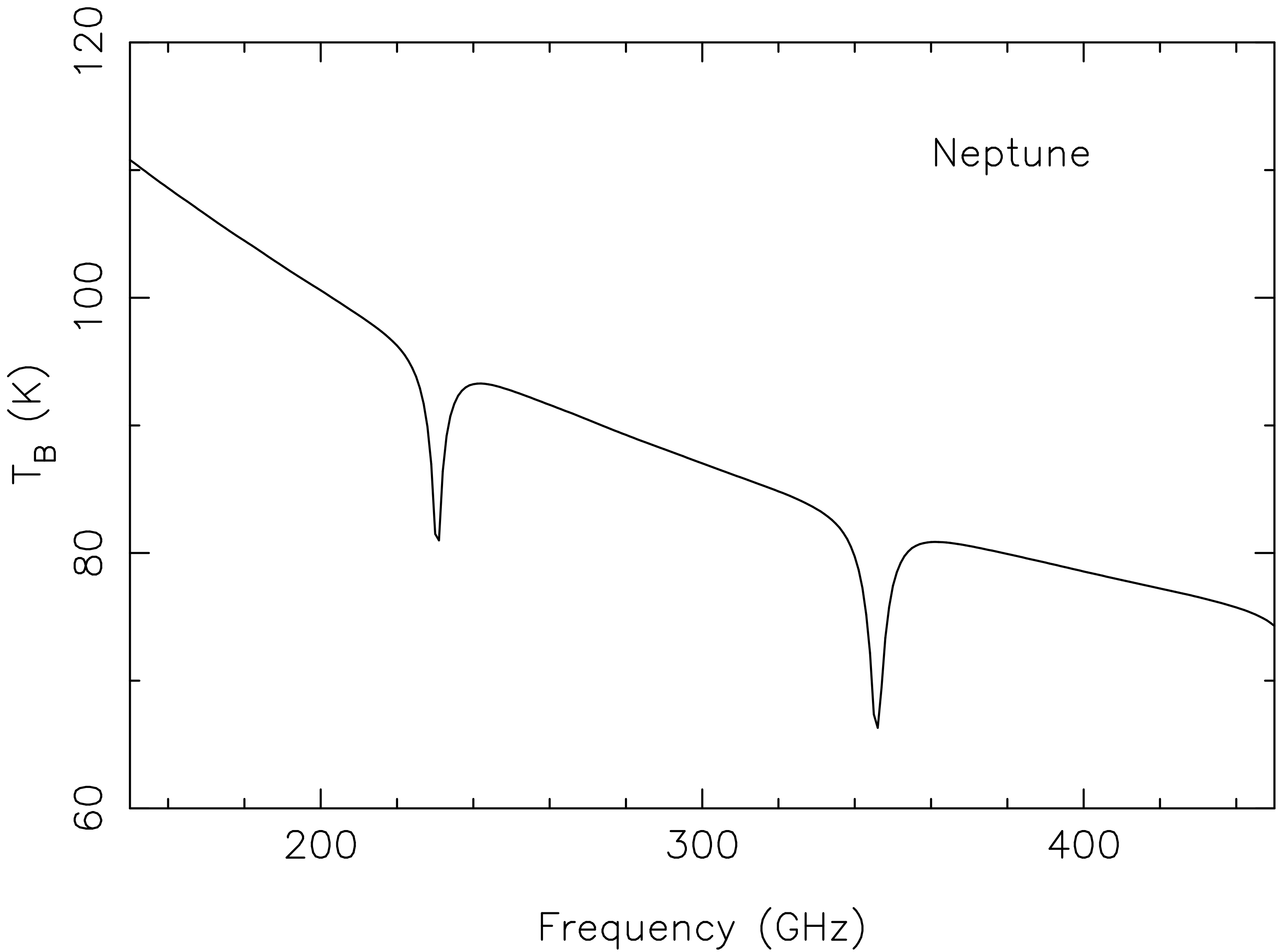


Maximum 'usable' baseline lengths at 1mm

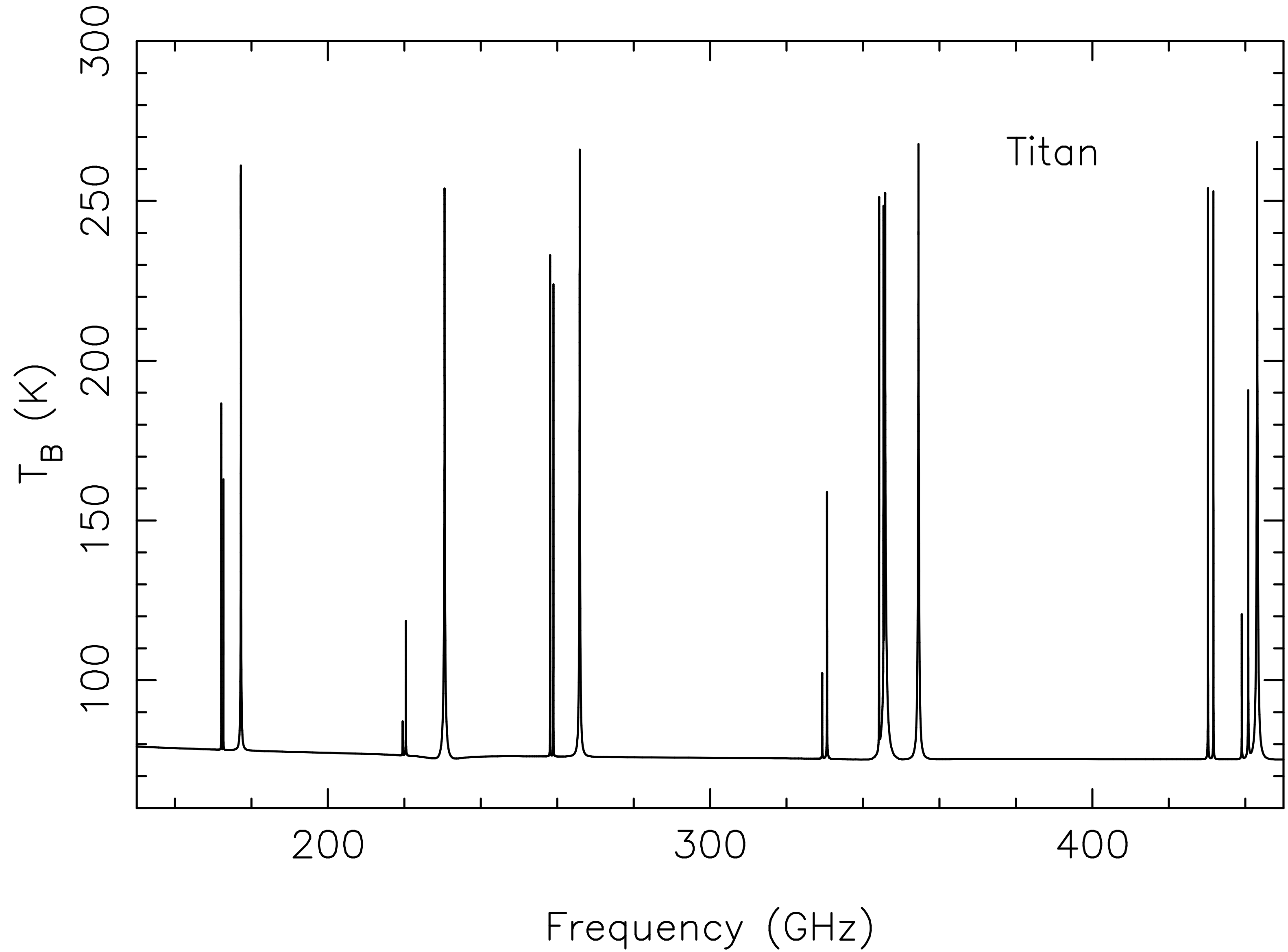
Source	Diameter	Baseline (m)
Jupiter	40″	4
Mars (oppo)	25″	7
Uranus	3.5″	50
Neptune	2.3″	70
Callisto	1.6″	100
Titan	0.8″	200

"That's no moon. It's a ~~space station~~ flux calibrator."

Spectral features



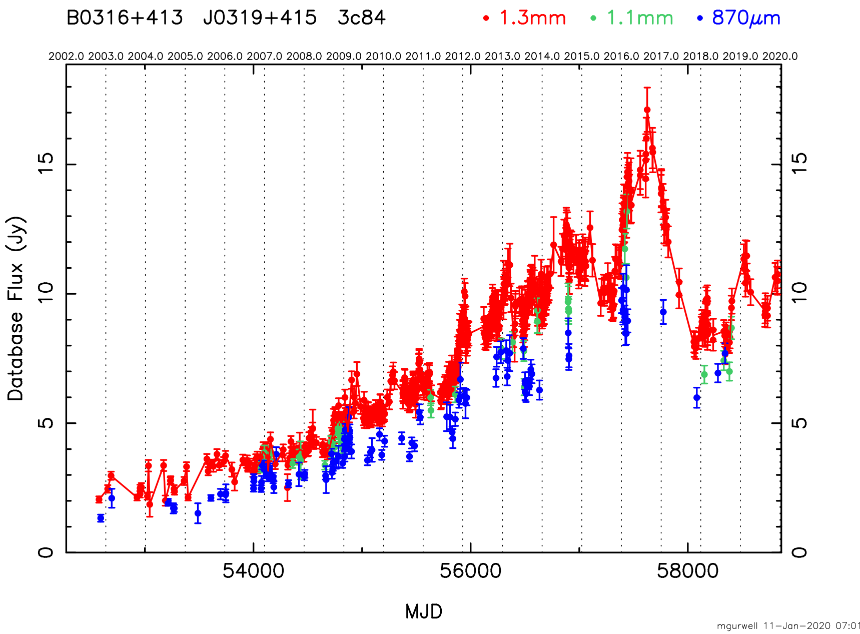
Spectral features

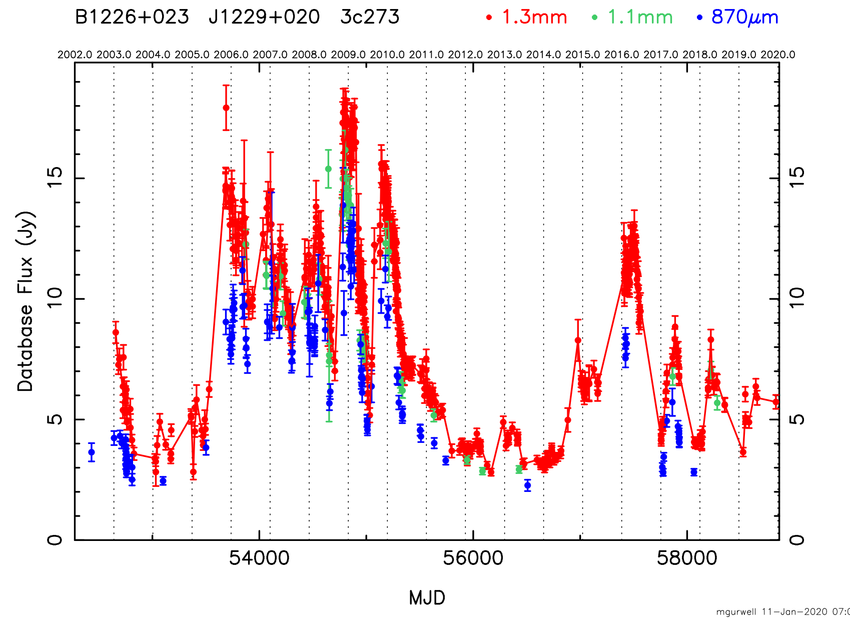


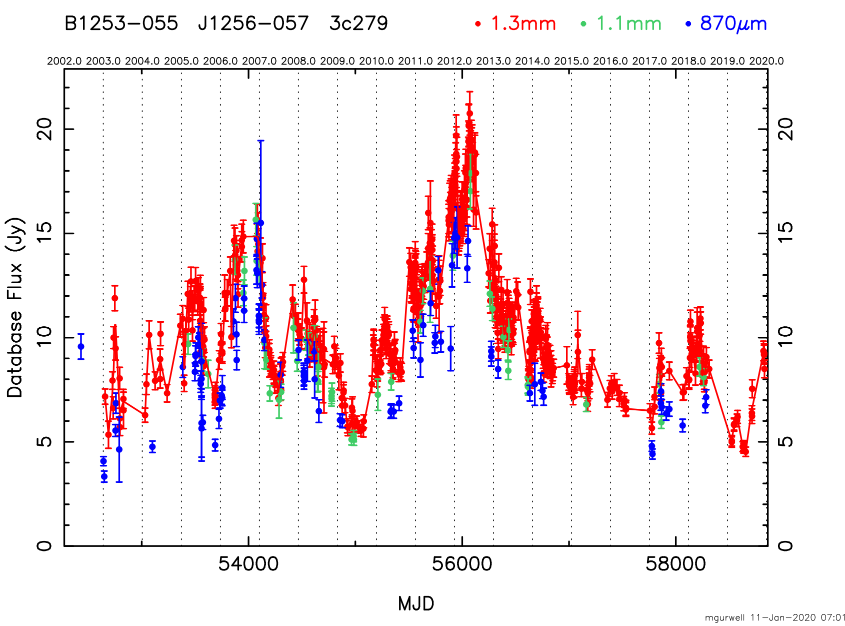
When No Flux Calibrator Data is Available

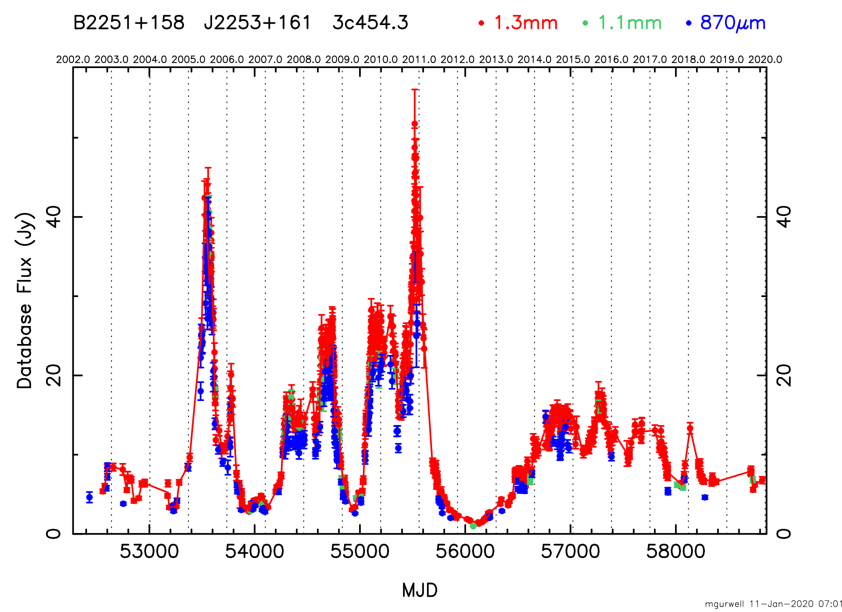
Sometimes, flux calibrator data is unusable or not obtained. What are your options?

- Rely on T_{sys} calibration – under good atmospheric phase stability, will underestimate flux due to uncalibrated efficiency losses, but will be within about 15-30%, depending on frequency
- Check if gain or passband calibrator sources have recently measured flux densities (may require interpolation)
  - SMA Database
  - ALMA Calibrator Database


B0316+413 J0319+415 3c84
• 1.3mm • 1.1mm • 870μm
2002.0 2003.0 2004.0 2005.0 2006.0 2007.0 2008.0 2009.0 2010.0 2011.0 2012.0 2013.0 2014.0 2015.0 2016.0 2017.0 2018.0 2019.0 2020.0
Database Flux (Jy)
0
5
10
15
54000
56000
58000
MJD
mgurwell 11-Jan-2020 07:01


B1226+023 J1229+020 3c273
• 1.3mm • 1.1mm • 870μm
2002.0 2003.0 2004.0 2005.0 2006.0 2007.0 2008.0 2009.0 2010.0 2011.0 2012.0 2013.0 2014.0 2015.0 2016.0 2017.0 2018.0 2019.0 2020.0
Database Flux (Jy)
0
5
10
15
54000
56000
58000
MJD
mgurwell 11-Jan-2020 07:01


B1253-055 J1256-057 3c279
• 1.3mm • 1.1mm • 870μm
2002.0 2003.0 2004.0 2005.0 2006.0 2007.0 2008.0 2009.0 2010.0 2011.0 2012.0 2013.0 2014.0 2015.0 2016.0 2017.0 2018.0 2019.0 2020.0
Database Flux (Jy)
0
5
10
15
20
54000
56000
58000
MJD
mgurwell 11-Jan-2020 07:01


B2251+158 J2253+161 3c454.3
• 1.3mm • 1.1mm • 870μm
2002.0 2003.0 2004.0 2005.0 2006.0 2007.0 2008.0 2009.0 2010.0 2011.0 2012.0 2013.0 2014.0 2015.0 2016.0 2017.0 2018.0 2019.0 2020.0
Database Flux (Jy)
0
20
40
53000
54000
55000
56000
57000
58000
MJD
mgurwell 11-Jan-2020 07:01

Question time!